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ANNUAL REPORT FOR JANUARY 1, 1963 TO JANUARY 1, 1964

BASIC SOLAR RESEARCH

Contract NOnr-1224(19) Nr ~~015-320~~ 013-205
NR 046-799

Department of Astronomy

The University of Michigan

Report submitted by

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During the calendar year covered by this report, the research activities supported by Contract Nonr-1224(19) Nr 015-320 have become more specialized than in previous years and have been principally concerned with solar flares. Investigations started before the report period have been continued, or concluded, and the intense concentration on flares has resulted from expansion and acceleration of studies that have been in progress in the Department of Astronomy for many years.

PERSONNEL

At the McMath-Hulbert Observatory, Mr. Arthur Miller and Mr. William Newbound continued as full-time employees paid from this contract. Mr. Charles Martens resigned September 1, 1963 to continue his graduate studies elsewhere. Mr. George Bergey interrupted his graduate study in astronomy at The University of Michigan to become a full-time employee on this project in June 1963.

In the Department of Astronomy in Ann Arbor, Miss Rebecca Parks, Mr. Edward Ungar, Miss Chie Takahashi, and Mr. Richard Moore have served as part-time graduate student assistants. Mrs. Maria Wentzel has continued as full-time assistant paid from the contract.

Throughout the year professional astronomers at several institutions supervised and participated without pay in the programs of research. These are:

The Department of Astronomy and the McMath-Hulbert Observatory of The University of Michigan - Mr. Clifford Bennett, Supervisor; Professor Guenther Eliste; Miss Ruth Hedeman, Research Associate; Professor Orren Mohler; Professor Helen Dodson Prince; and Professor Richard Teske.

The Perkins Observatory of The Ohio State University - Professor Walter E. Mitchell, Jr.

Observatoire Cantonal, Genève, Suisse - Professor Edith A. Müller.

Los Alamos Scientific Laboratory - Dr. J. Paul Mutschlecner.

RESEARCH PROGRAMS

The Study of Solar Flares: Initial Survey and the Organization of the Spectroheliographic Records of Solar Activity

In 1958, special spectroheliographic records consisting of monochromatic solar photographs of active regions on the disc were begun with the 50-foot solar tower telescope. Each photograph was made with a narrow band of radiation (usually 0.3 angstroms, or less, in width) selected from the solar spectrum systematically in the neighborhood of, and including, the center of the C (H alpha, 6563 angstroms) and K (Ca II, 3933 angstroms) lines. The band centers for a series of photographs were changed systematically from a position in the spectrum several angstroms shorter than the wavelength of the central spectral line to a position several angstroms longer. A series of photographs of the solar disc made with radiation selected at intervals from the short wavelength side to the long wavelength side of a selected spectral line is referred to as a wavelength sweep.

Wavelength sweep records exist for 1958-1961 in the form of photographs of sections of the solar disc on about 8,000 feet of 35 millimeter motion picture film. These records have been examined picture by picture and organized for study. The positions of all regions photographed on the solar disc have been noted; an approximate time for each photograph in the series constituting a wavelength sweep has been recorded; and a journal of general comments on the phenomena photographed and the quality of the observation has been compiled in a series of bound notebooks totaling about 1800 pages.

In another listing, chronograph times to the nearest second have been recorded for all of the observations in 1958-1961.

A card catalogue of specific events shown on the wavelength sweeps has been completed for the above interval and the information it contains is summarized in Table 1.

Table 1

SUMMARY OF SPECIFIC EVENTS

McMATH-HULBERT WAVELENGTH SWEEPS FOR 1958-1961

SPECIFIC EVENT	NUMBER OF RECORDS				
	1958	1959	1960	1961	Total
Pre-flare observations	24	115	55	33	227
Flares	52	178	77	58	365
Ejections from flares	1	16	5	6	28
Flares with loops	0	4	3	5	12
Large flares without loops	0	11	2	4	17
"Points"	20	34	34	25	113
Filaments, active or otherwise interesting	4	30	30	21	85
Active dark flocculi	3	63	73	38	177
Limb events not called flare	0	13	11	4	28
Dark absorption in wings of K-line	7	3	1	5	16
Bright features in wings of K-line (not points)	7	54	28	14	103

The most interesting of the phenomena are being reproduced on photographic paper prints so that they may be studied easily. At the end of November 1963, the catalogue of photographic paper prints covered 600 wavelength sweeps made in May and July 1959, and more than 100 wavelength sweeps of the region producing polar cap absorption in July 1961.

A projector that will be used for visual comparison in detail of individual frames in the wavelength sweep records has been designed and constructed.

The Study of Solar Flares: Solar Phenomena Associated with Polar Cap Absorption (PCA)

Flares associated with PCA. A survey was made of the flares associated with all known cases (51) of Polar Cap Absorption during the five-year interval 1957-1961. The results of this survey were reported in October 1962, at the 1962 Midwest Cosmic Ray Meeting in Minneapolis, and at the 1963 Tucson meeting of the American Astronomical Society. A summary of this report follows.

The 51 known cases of polar cap absorption during the five-year interval 1957-1961 have been ranked on the basis of reported maximum absorption. The 18 greatest PCA events were associated primarily with flares of importance 3 and 3 plus, all within 60° of the central meridian of the sun. In the five years here studied, however, there were 104 flares of importance 3 and 3 plus, but only one-third of these were followed by PCA.

The occurrence of Type IV radio frequency emission is one of the most general characteristics of PCA flares. Such radiation may be necessary for the occurrence of PCA, but there were 123 flares with Type IV continuum emission and fewer than one-third of these were followed by PCA.

Although strong emission at 10 cm is another general characteristic of PCA flares, only one-third of the flares with 10 cm bursts showing fluxes of radiation greater than or equal to 500×10^{-22} watts per square meter per cycle per second were followed by PCA. For most PCA flares, the maximum emission at 10 cm follows the maximum at H alpha, and this relationship can be used successfully to separate PCA from non-PCA flares. Ninety per cent of the flares with 10 cm flux greater than or equal to 500×10^{-22} watts per square meter per cycle per second, and with maximum following H alpha maximum were PCA flares.

Photographic records continue to provide evidence that PCA flares occur over major spot umbrae. Such a flare does not necessarily start over an umbra, but usually spreads to it as the flare develops. Records for 21 of the 51 PCA flares have been seen. They indicate umbral coverage in each case.

The only sufficient condition yet discovered for PCA is the simultaneous occurrence of all of the major characteristics of PCA flares - i.e., flare importance 3 plus, large umbra covered, strong Type IV radio emission, and strong flux at 10 cm in the form of a burst with maximum after H alpha maximum.

Regions with PCA flares. Efforts to predict the occurrence of flares that eject high energy particles will be greatly assisted if the distinguishing characteristics of regions in which PCA flares develop can be recognized. Proton-producing flares have appeared, in general, in active, flare-rich regions containing large, complex sunspots (sunspot magnetic field type gamma, and beta-gamma). Only relatively small fractions of the total number of sunspot regions with these characteristics have produced flares followed by an observation of protons in the vicinity of the earth. Table 2, below, summarizes the relationships.

Table 2

NUMBER OF REGIONS WITH GIVEN CHARACTERISTICS COMPARED TO REGIONS WITH PROTON FLARES

CHARACTERISTIC THAT APPEARS TO FAVOR THE OCCURRENCE OF PROTON FLARES	REGIONS WITH SPECIAL CHARACTERISTIC		TOTAL NUMBER REGIONS WITH PCA FLARES FOR INDICATED YEARS
	Total No.	Number With PCA Flares	
Flare-rich 1957-1961 (25 most flare-rich in each year)	125	27	34
Flares with Type IV emission 1957-1961	70	26*	34
Fifty largest sunspots 1957-1960 (Mount Wilson)	50	11	31
Spots with area $\geq$ 1000 millionths of hemisphere 1955-1960 (Mount Wilson)	75	11	34
$\beta\gamma$ spots 1955-1960 (Mount Wilson)	61	14	34
γ spots 1955-1960 (Mount Wilson)	32	9	34
$\beta\gamma$ or γ spots 1955-1960 (Mount Wilson)	93	23	34
$\beta\gamma$ or γ spots and spot area $\geq$ 1000 millionths of hemisphere 1955-1960	32	12	34

*It is possible that this number should be larger because PCA flares occurred in eight regions at times when dynamic spectra were not being obtained.

In June 1961, at a meeting called by NASA at the High Altitude Observatory of the University of Colorado, Professor Prince pointed out that the then known PCA flares had occurred mainly in long-lived calcium plages during their second, or later, appearances on the visible hemisphere of the sun. According to McMath-Hulbert records, subsequent years have failed to provide instances of major proton events with flares that have occurred in calcium plages during their first appearance on the sun's disk. The age of the center of activity apparently plays some role in creating circumstances favorable for the ejection of high-energy particles at the time of great flares, or for the arrival of particles in the vicinity of the earth.

Consideration of the age, or maturity, of an active center in conjunction with other characteristics associated with PCA flares strengthens the evidence that long life may be a necessary aspect of a region before major flares, even with strong Type IV emission, produce high-energy protons detectable in earth's neighborhood by methods currently in use.

Diagrams showing number versus age of calcium plages (not the age of the associated spots) in which PCA flares have taken place; the distribution by age of the regions with flares emitting Type IV radiation with distinction between PCA and non-PCA regions; corresponding data for the regions with the largest sunspots have been prepared.* Graphical studies have been made for other characteristics of PCA flares and regions, and in every case the introduction of the age of the region has been helpful in sharpening the distinction between proton-producing flares and relatively similar flares without associated PCA at the earth.

Current situation in regard to the prediction of polar cap absorption. If complete and excellent photographic, visual, and radio-frequency observations are immediately available, it should be possible to recognize flares that will be followed in a small number of hours by major proton events. Minor events may be missed and a small amount of over-warning would result.

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*Data for the largest sunspots are based on the Mount Wilson yearly summaries of large sunspots with area greater than 1000 millionths of the hemisphere. They are complete only through 1960.

The occurrence of one PCA flare in a region is good warning for further PCA flares in the same region, either during the presence of the region on the visible hemisphere, or during reappearances in subsequent solar rotations.

Anticipation of proton events by more than a few hours, or by events other than the prior occurrence of a proton flare, seems to require better understanding of the characteristics of the regions in which the proton flares occur, the patterns of growth and development of the regions, and the characteristics that distinguish the PCA from the non-PCA regions. Attempts at improvement are considerably hampered by the disappearance of active regions for two-week intervals as a result of the sun's rotation. Observational data must be extrapolated in an attempt to deduce whether or not a particular region will diminish, grow, or remain relatively unchanged during the thirteen days of invisibility. Furthermore, at present, the study of regions does not give as much weight to the role of sunspots as might be desirable because detailed information about the growth and development of sunspots in area and magnetic characteristics does not exist.

The age of regions in which flares occur is extremely helpful in the prediction of PCA events, since major PCA events have not been associated with regions in their first solar rotation. Possibly this circumstance reflects conditions in the earth-sun system rather than a situation related to the production of protons in a flare. This possibility is under repeated re-examination as these studies continue.

The Study of Solar Flares: Relative Intensities of Flare Emission Lines

During the IGY a series of flare spectra were made with the Wadsworth spectrograph of the McMath-Hulbert Observatory. Dr. Elste has reviewed these observations for use in constructing a catalogue of the relative intensities of flare emission lines. Since the resolving power of the spectrograph is low, only estimates of line widths are possible, but the relative intensities can be established with considerable precision and measurements to this end are underway.

The Study of Solar Flares: Other Research Programs Relating to Flares

Dr. Teske has studied high-resolution spectra in the H alpha region that were secured during the great cosmic-ray flare of November 12, 1960. The physical structure of this flare, as indicated by the H alpha emission, closely resembled that deduced by other investigators for other very great H alpha flares

During the months of March and May 1963, Dr. Prince visited observatories at the Fraunhofer Institute, Arcetri, Meudon, and Dunsink. Photographs of the solar disk were examined for the hours before sunrise at the McMath-Hulbert Observatory on the days that saw the occurrence of PCA-associated flares and also on the days of occurrence of great flares without PCA. The observations tended to strengthen evidence that the greatness of sunspots and their proximity to the flare emission play some part in the differentiation between great flares with, and without, major proton emission. In the course of her three-months absence from the McMath-Hulbert Observatory, Dr. Prince had the privilege of discussing solar problems of mutual interest with many astronomers including: Drs. Kiepenheuer and Bruzek at the Fraunhofer Institute; Professors Righini and Ballario at Arcetri; Professor Rösch at the Pic-du-Midi; Drs. Michard, Pick-Gutman, Servajean, Mme. Martres and M. Olivieri at Meudon; Professor Ellison, Dr. McKenna and Dr. Reid at Dunsink; and most especially with Dr. and Mme. d'Azambuja, now retired, but still the most experienced observers of solar activity.

Dr. Teske has directed the use of the McGregor solar tower and vacuum spectrograph during the last year for the measurement of magnitude and polarity of magnetic fields in sunspots and adjacent regions. These measurements have been used for the classification of sunspot groups according to the McMath-Hulbert understanding of the Mount Wilson system, and also for detailed studies of the structure of magnetic fields within some of the large sunspots that appeared in 1963. Analysis of the measurements is being continued.

At the request of the Chairman of the Inter-Union Committee on Solar-Terrestrial Relationships, Miss Hedeman and Dr. Prince prepared a review manuscript entitled: "Problems of the Differentiation of Flares with Respect to Geophysical Effects." The review attempted an evaluation of the general

relationships between flares and possibly associated ionospheric and geomagnetic disturbances for the five years 1957-1961. The manuscript is being published in the X Report on Solar-Terrestrial Relations of the Inter-Union Commission on Solar and Terrestrial Relationships.

The wavelength sweep records, currently under organization for more extensive analysis under this contract, provided data used by Dr. Prince and Miss Redeman for a report, "Moving Material Associated with the Flare (3 plus) of July 16, 1959," presented at the GSFC - American Astronomical Society Symposium on the Physics of Solar Flares, October 1963. The observations provide evidence for ejections in the premaximum and early stages of the flare and systems of loop prominences and descending material in the late phases. The inferred prominence motions accompanying this great flare on the solar disc are consistent with the prominence motions photographed at the times of certain great flares at, or near, the limb of the sun. Additionally, the wavelength sweep spectroheliograms showed that the activation of a relatively distant filament in the early stages of the 1959 July 16 flare took place during the displacement of the H alpha absorption by the apparently intact filament. The H alpha absorption by the filament is first displaced about one angstrom to the longer wavelengths and this is followed by a similar displacement to the shorter wavelength side of the H alpha line. The displacements imply down-up motions of the filament and they were repeated before the filament stabilized. Similar motions, first down, then up, were recorded during the activations of filaments associated with the flare of 1960 June 25^{d} 20^{h} 39^{m}.

Basic Solar Research: The Small-Scale Structure of Selected Fraunhofer Lines

Dr. Teske has analyzed spectrum photographs made especially for the study of the variations with time of the fine structure in the Fraunhofer lines. A number of series of spectra were exposed, each of which was guided at a precise position on the solar image. Measurements of the structure in the line indicated oscillatory motions in the granulation field from which a quasi-period of 270 seconds was deduced. Detailed analysis of a single series of fine spectra indicated that photospheric elements showing a temporal period are standing waves in which quasi-periodic oscillations are modified by radiative leakage of energy. Statistical analysis of the coherence of the depth, half-intensity widths,

equivalent widths, and small-scale structures in the Fraunhofer lines implied that the cooler photospheric elements are in more turbulent motion than the hotter cells.

Absorption lines in the solar spectrum sometimes show variations in width across the photospheric faculae. Dr. Teske has secured more than 100 spectrograms in facular regions for the study of this effect and the comparison of spectrum line widths within and outside of faculae. Approximately one-half of the material available has been measured and analyzed.

A related study is based on the observation that large, local shifts in the Fraunhofer lines are known to be muted in the calcium plages. Dr. Teske has accumulated spectra taken under unusually excellent seeing conditions for an investigation of the large shifts and their implications with regard to the plage-facula phenomenon.

Basic Solar Research: The Decrease in Intensity at the Extreme Solar Limb

Drs. Elste and Teske and Mr. Bennett, assisted by members of the McMath-Hulbert Observatory staff observed the partial solar eclipse of 1963 July 20 at Lake Angelus using the McGregor solar tower and vacuum spectrograph. Observations that will be used for the determination of the decrease in intensity at the extreme solar limb were recorded photographically and photoelectrically in a number of spectral regions near the maximum partial phase of the eclipse. Dr. Elste will apply these observations to the determination of variations in the sun's continuous spectrum at the solar limb. From this result it will be possible to make an estimate of electron temperatures in the upper solar atmosphere.

Basic Solar Research: Investigations of Center-to-Limb Variation of Weak Lines of Iron and Oxygen

Dr. Elste has begun a theoretical study of the sun's energy distribution at the center of the disc and of the solar limb-darkening. A new temperature model of the solar atmosphere is being computed and detailed computations of the wavelength dependence of the continuous absorption coefficient are in progress. The results of the computations will be applied to the study of the weak lines of iron and oxygen. It appears that the generally accepted values

for microturbulence in the solar atmosphere are far too large and that the essential mechanism for line broadening is macroturbulence. In order to confirm this result, the wings of strong lines are being measured. This will make possible a derivation of the numbers of absorbing atoms in the lower level of the strong line. The equivalent widths of weak lines arising from the same level can be used to eliminate the effects of microturbulence and the velocity field of the macroturbulence can be found from analysis of the strong line profiles. The results for the macroturbulence will be compared directly with the observed structures of the strong lines.

Basic Solar Research: The Wavelengths of the Lines in the Solar Spectrum

Dr. Mohler has generally supervised a continuing study of the wavelengths of solar lines in the 3000 angstrom and 10,000 angstrom spectral regions. Dr. Walter E. Mitchell, Jr., is in immediate charge of the wavelength determination and line identification in the 3000 angstrom region. For this work he has used the ONR spectrometer installed in the Snow telescope on Mount Wilson. Line identifications in the 10,000 angstrom regions are being carried forward by Mrs. Wentzel and Chie Takahashi in close collaboration with Dr. Mohler. The line identifications in the 10,000 angstrom region are based on tracings made at the High Altitude Observatory, Jungfraujoch, Switzerland, by Professor M. Migeotte of Liège University.

Basic Solar Research: The Chemical Abundances in the Solar Atmosphere

Drs. Edith Müller and J. Paul Mutschlecner have continued their studies of the abundances of the various elements in the solar atmosphere. Mutschlecner devised a routine for the computation of abundances in which the numerous parameters could be varied independently. This routine was applied by Mutschlecner in his thesis to the determination of the relative abundances of the trace elements lithium, beryllium, and lead, and by Mutschlecner and Müller to a study of the effects of non-equilibrium conditions on the determination of abundances. Both of these studies emphasize the necessity for improved laboratory values of the oscillator strengths if significant advances in precision are desired.

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